

# **An Investigation of non-Bragg Scattering from the Sea Surface**

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## **LONG-TERM GOALS**

The long-range objective of this work is to develop a detailed characterization of non-Bragg scattering from a wind-roughened water surface, or a breaking wave region, and establish a link between radar observations and physical processes, leading ultimately to a more complete, physically-based model for predicting radar scattering from the sea surface.

## **OBJECTIVES**

Our objective is to characterize non-Bragg scattering from the air-sea interface as a function of environmental conditions and radar parameters to improve our understanding of the mechanisms responsible for non-Bragg sea surface scattering and to develop models appropriate for this type of scattering. Most predictive models of radar backscattering from the sea surface rely on Bragg-based characterization of sea surface scattering. Evidence suggests that although Bragg scattering from the sea surface accounts well for many observations, some phenomena exist that it is unable to explain, indicating that it does not adequately represent all of the physical processes. A physically-based model of sea surface scattering that takes into account both Bragg and non-Bragg scattering will ameliorate this situation.

## **APPROACH**

Our approach is to study non-Bragg scattering from the air-sea interface using existing data sets that include both environmental and radar measurements. Our investigations focus on the following issues:

Non-Bragg Criterion. The ratio of normalized radar backscatter from the roughened water surface ( $\sigma_{HH}^0/\sigma_{VV}^0$ ) is used as a criterion to identify and separate the Bragg and non-Bragg scattering populations, because Bragg scattering theory predicts that  $\sigma_{VV}^0$  is greater than  $\sigma_{HH}^0$  under all

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circumstances. Therefore,  $\sigma_{HH}^0/\sigma_{VV}^0 > 1$  provides a robust definition of processes that cannot be explained by Bragg scattering theory. In order for this criterion to be meaningful, however, it is necessary to enforce rigorous conditions of simultaneity and coincidence of the HH and VV measurements, otherwise it is possible that the Bragg scattering criterion be violated even though the scattering is Bragg. In evaluating the polarization ratio, two definitions are possible:  $\langle \sigma_{HH}^0 \rangle / \langle \sigma_{VV}^0 \rangle$ , and  $\langle \sigma_{HH}^0 / \sigma_{VV}^0 \rangle$ , where  $\langle \rangle$  denotes averaging. These two quantities yield appreciably different results for a given observation period. We are investigating these two definitions of the polarization ratio, particularly with respect to bias issues, to determine which definition is most appropriate for use in this study.

Down-sampling or averaging. It has been shown that down-sampling or averaging of the radar measurements governs the observed frequency of non-Bragg events. For instance, Jessup et al. (1991) noted that the number of non-Bragg returns observed in a given time interval depended strongly on integration time. Rufatt (1999) further investigated this issue and found that both the shape of the probability distribution function and the sample mean depended (by a factor of two in some cases) on the degree of down-sampling applied to the raw radar observations. For this reason, we require that all radar measurements used in this investigation have averaging times that are significantly less than the inherent decorrelation time of the return.

Correlation with radar and environmental parameters. The incidence of non-Bragg sea surface scattering varies as a function of radar configuration (viewing geometry and frequency) and environmental conditions. This study investigates the following topics: correlations between non-Bragg backscattering and regions of macro- and micro-breaking waves; relationship between non-Bragg scatter and long wave phase; relationship between non-Bragg backscatter and sea spikes, short-lived, anomalously strong returns that have their most striking manifestation in the horizontally polarized return. Sea spikes have been correlated with wind stress, an unstable atmospheric boundary layer, unsteady wind, swell, fetch, and water depth. We will study the behavior of both the polarization ratio and the incidence of non-Bragg scattering from the air-sea interface as a function of these environmental parameters.

Two researchers have proposed models for predicting non-Bragg sea surface scattering. Rufatt (1999) developed a model applicable in cases with no swell, which predicts the number of non-Bragg events per unit time as a function of wind speed or significant wave height. Phillips (1988) modeled the total radar backscatter from the sea surface as the sum of Bragg and sea spike contributions, and proposed different physically-based models for each (a linear relationship between  $\sigma^0$  and the wind friction velocity,  $u^*$ , for Bragg ripples, and a cubic relationship between  $\sigma^0$  and  $u^*$  for breaking waves). We will validate both of these models for a variety of data sets that comprise a range of radar collection geometries and environmental conditions. Where appropriate, we will propose modified forms of the above-mentioned models, and/or suggest alternative models for non-Bragg scattering from the air-sea interface.

## **WORK COMPLETED**

Work began on this project in January 2001, so the research is still at an early stage. Thus far, we have been analyzing data from the SAXON-FPN experiment conducted during the month of November 1990, and have obtained a complete copy (~50 GBytes) of the radar and environmental measurements acquired during this experiment. For the entire month, several times per hour, 5-minute sequences of

radar measurements were obtained at a data rate of 3 KHz, and once per hour, calibration coefficients and environmental measurements were obtained. The radar data includes horizontally and vertically polarized radar observations acquired simultaneously at Ka, Ku and X-band, with an incidence angle of approximately 45°. Availability of calibration data constrains us to focus initially on the Ka- and X-band data sets.

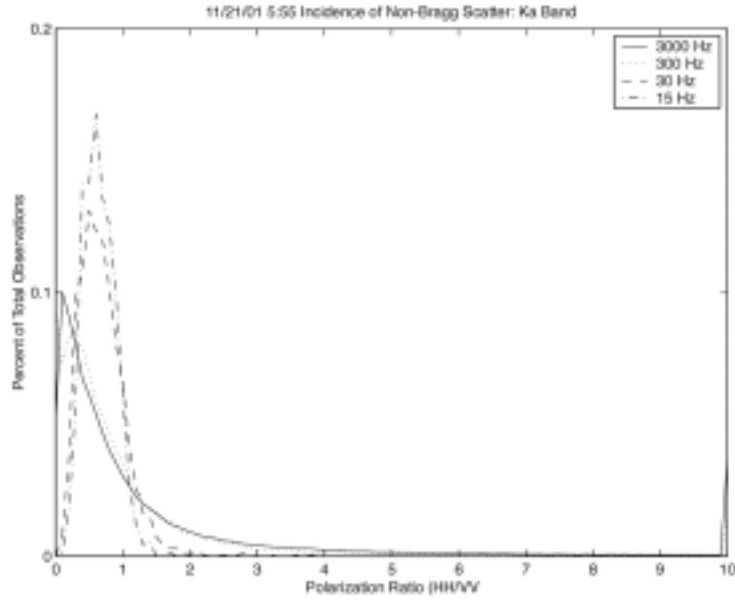
Due to the rigorous requirements for simultaneity and coincidence in defining the polarization ratio, for each frequency, we must ensure that the two antennas (V and H polarization) were looking at same spot on the ground. To this end, we have examined the antenna patterns for the Ka-band system, and found near-perfect overlap for the two beams. Preliminary examination of the X-band beam patterns shows good, but not perfect overlap. This issue is currently being investigated in greater detail.

We are studying the effects of averaging or down-sampling on the presence of data spikes in the two channels, and its impact on the observed frequency of non-Bragg events. We have analyzed several sequences of radar measurements from Phase I of the SAXON-FPN experiment, which span a range of environmental conditions, and have found evidence that the distribution of polarization ratio varies appreciably with sample rate. To determine the significance of these trends, and to identify the statistical characteristics of non-Bragg scattering from the sea surface as a function of sample rate, radar frequency and environmental conditions, we will analyze the complete SAXON-FPN Phase I data set. In addition, we will analyze the SAXON-FPN Phase II data set, which will enable us to extend our findings to a broader range of angles of incidence.

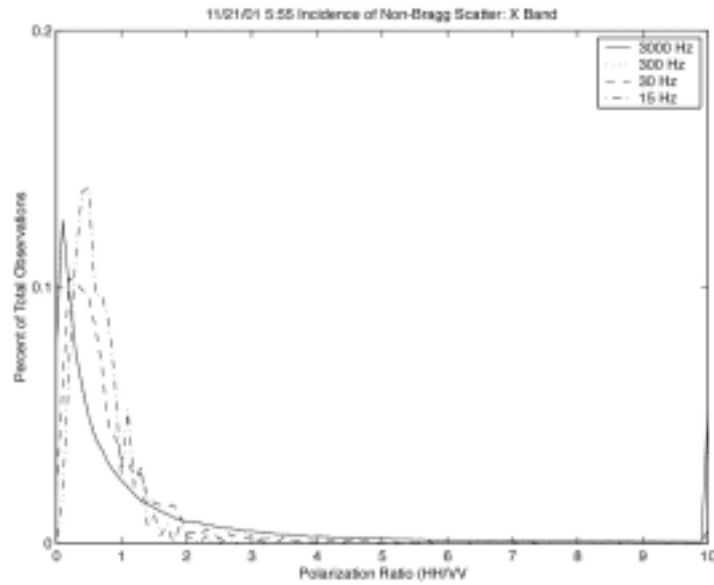
## RESULTS

Figures 1 and 2 illustrate the effects of down-sampling on the incidence of non-Bragg sea surface scattering. In Figure 1, the polarization ratio  $\langle \sigma_{HH}^0 / \sigma_{VV}^0 \rangle$  is depicted for the Ka-band measurements from day 21 of the experiment. For this case, the wind speed was 10 ms<sup>-1</sup>, the wind direction was 50°, the significant wave height was 1.3 m, and the boundary layer was unstable: the water temperature was 10.1°C and the air temperature was 5.6 °C. Figure 2 depicts the coincident X-band sea surface measurements.

Both figures clearly show how the shape and the peak of the distribution, and the height of the tails, vary with sample rate. The trends for these results are consistent with the findings of Rufatt (1999), but encompass a broader range of sampling frequencies. These results show that at the full sample rate, there is considerable non-Bragg scatter from the sea surface at both X- and Ka-band, which decreases as the data are down-sampled. The following table summarizes the mean and the standard deviation for the percent of non-Bragg scattering observed for the six cases analyzed thus far, encompassing wind speeds between 5 and 10 ms<sup>-1</sup>. These analyses will be performed for the full SAXON-FPN Phase I and II data sets, and will enable us to identify the optimal sample rate for the identification and study of non-Bragg scattering from the air-sea interface.



**Figure 1. Effect of Down-sampling on non-Bragg Scatter at Ka-band.  $\langle \sigma_{HH}^0 / \sigma_{VV}^0 \rangle < 1$  corresponds to Bragg scattering. [The percent of the total return associated with non-Bragg scattering decreases with increased down-sampling.]**



**Figure 2. Effect of Down-sampling on non-Bragg Scatter at X-Band.  $\langle \sigma_{HH}^0 / \sigma_{VV}^0 \rangle < 1$  corresponds to Bragg scattering. [The percent of the total return associated with non-Bragg scattering decreases with increased down-sampling.]**

	<b>Ka average % non-Bragg</b>	<b>Ka std. dev. non-Bragg</b>	<b>X average % non-Bragg</b>	<b>X std. dev. non-Bragg</b>
3000 Hz	0.32	0.03	0.35	0.04
1000 Hz	0.31	0.03	0.34	0.04
300 Hz	0.26	0.03	0.34	0.04
30 Hz	0.11	0.03	0.25	0.05
10 Hz	0.05	0.01	0.17	0.04

## **IMPACT/APPLICATION**

This project will lead to an improved understanding of the physical processes responsible for observed radar returns from the sea surface as a function of radar viewing parameters and viewing conditions.

## **TRANSITIONS**

The results of this project have not yet been transitioned for operational use.

## **RELATED PROJECTS**

This project is directly related to NASA scatterometers, such as QuikScat, and is relevant to the study of sea surface scattering, particularly at high wind speeds.

## **REFERENCES**

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